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BULLETIN 226.

NOTE ON THE ACCURACY OF BUSHEL WEIGHT DETERMINATIONS.*

By Clarence W. Barber.

In tests of varieties of grain it is essential to determine the weight per measured bushel of the grain produced by different varieties. For this purpose there is commonly used the standard grain weighing device, consisting of a one or two quart brass bucket suspended from a scale of the steel yard type. This measuring apparatus is often referred to as the grain tester. One is shown in figure 42. The beam for a two quart bucket is marked with three scales or series of divisions. One scale is in ounces and pounds allowing a little more than four pounds as the total capacity of the bucket; the second series of divisions gives the percentages of four pounds; the third, represents directly the weight in pounds (up to 65) per measured bushel. Because of the finer divisions the greatest accuracy in weight determinations by this device is attained through using the percentage scale and calculating therefrom the weight of a bushel in pounds. This bucket holds one-sixteenth of a bushel; its total capacity in weight is four pounds. Hence to derive the weight in pounds per measured bushel it is only necessary to multiply the percent by the factor 64.

Having frequently to use this standard bushel measure in the determination of the weight per bushel of oats grown in the variety tests conducted by this Station, the necessity of carrying out a particular scheme of manipulation soon made itself apparent. An inquiry made to the U. S. Bureau of Standards brought the following information about the use of the grain

* Papers from the Biological Laboratory of the Maine Agricultural Experiment Station No. 61.

tester. "So far as the Bureau has any knowledge on the matter, there is very little care or uniformity of method used in filling the bucket with grain, although without doubt, it is a matter to which greater attention should be given as there is a decided difference in the amount of grain that may be contained in a measure according to which it is struck off level as it falls into the bucket or is first shaken down. The most common practice in the matter is, probably, to merely dip the bucket into the grain to fill and then strike off the grain as it lies." With the aim of obtaining data relative to the methods of handling this device a series of weighings of one variety of oats, namely the Lincoln, were made. It should be said that the Lincoln oat is medium in size, plump and generally free from awns.

The lot of oats amounting to five bushels from which the data presented in this paper were collected was contained in a bin 3 ft. 10 in. long by 2½ ft. wide and 2½ ft. deep. Before beginning to take weight records the oats were thoroughly stirred and piled in one end of the bin. For each weighing the bucket was filled with the grain in one end of the bin. After recording the weight the grain was emptied in the opposite end of the bin. Hence the bucket was filled for each determination with grain from one end only of the bin until all the grain in that end was removed to the opposite end. Then the grain was again thoroughly stirred or mixed and piled in one end of the bin as in the beginning. One hundred weighings, the distribution of which is shown in table 1, were made according to each of four methods. All weighings were obtained during one day by one person.

The procedure in the different methods was as follows:

Method I. The grain was poured into the bucket filling the same rounding full and was not settled in any way. Then the top was levelled off as follows: In each method a beveled straight edge laid flat on the rim of the bucket was used to smooth off the top grains in order to ensure the surface of the grain being in the same plane with the rim. The straight edge should be moved in a zigzag movement across the surface and should not be drawn directly across, for such a force drags out many grains beneath the plane of the rim leaving the bucket incompletely filled.

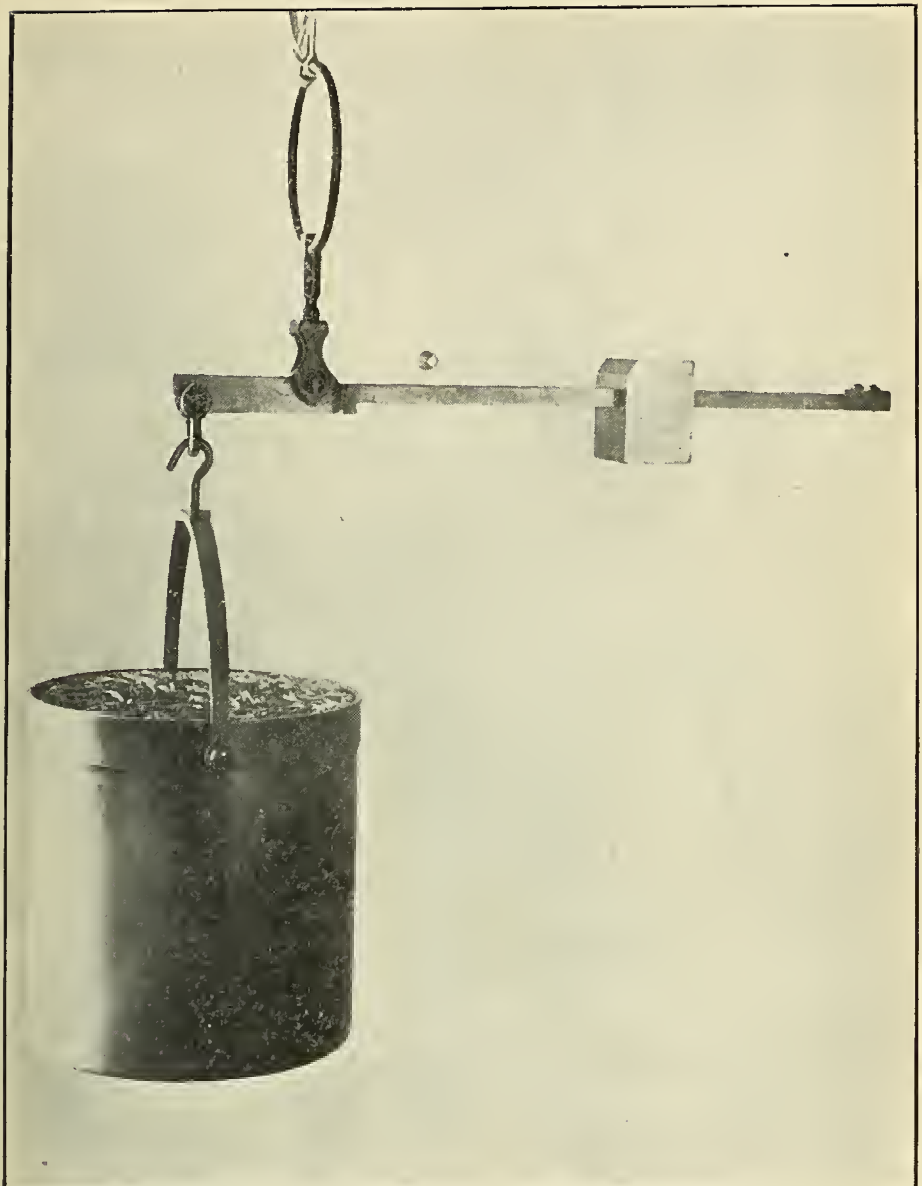

FIG. 42. Standard grain tester in position for determining the weight per measured bushel of grain.

Method II. The bucket was filled rounding full by dipping it directly into the grain. The grain was not settled in any way. Then the top was levelled as in Method I.

Method III. The bucket was filled rounding full by dipping it into the grain and then shaken down once. After shaking the top was smoothed off as in Method I.

Method IV. The grain was poured into the bucket filling it rounding full and settled by shaking down five times. After this the straight edge was used to level off the top surface as in Method. I.

In case shaking settled the grain below the rim of the bucket more grains were poured on top and then levelled off. In shaking, the bucket was held firmly with both hands. Each shaking involved a short, quick downward movement of the bucket brought to an abrupt stop.

TABLE I.

Frequency Distributions for Variation in the Percentage Determinations of Weight per bushel of Oats.

CLASS. Per cent.	I. Grain poured into bucket. Not shaken or settled.	II. Bucket filled by dipping it into the grain. Not shaken or settled.	III. Bucket filled by dipping it into the grain shaken once to settle grain.	IV. Grain poured into the bucket. Shaken down 5 times
52.0-52.4.	7	–	–	–
52.5-52.9..	6	–	–	–
53.0-53.4..	3	–	–	–
53.5-53.9..	27	–	–	–
54.0-54.4..	27	–	–	–
54.5-54.9..	16	–	–	–
55.0-55.4..	11	–	–	–
55.5-55.9..	3	3	–	–
56.0-56.4..	–	8	1	–
56.5-56.9..	–	3	1	–
57.0-57.4..	–	18	5	–
57.5-57.9..	–	27	16	–
58.0-58.4..	–	20	27	–
58.5-58.9..	–	10	19	1
59.0-59.4..	–	8	22	3
59.5-59.9....	–	2	6	18
60.0-60.4...	–	1	2	36
60.5-60.9....	–	–	1	31
61.0-61.4....	–	–	–	10
61.5-61.9...	–	–	–	1
Totals	100	100	100	100

The results derived from the data collected in each method are tabulated in table 2. Here it will be noted that the mean weight per bushel increases 2.4 lbs. or 7 percent when the bucket is filled by dipping it into the grain as compared with

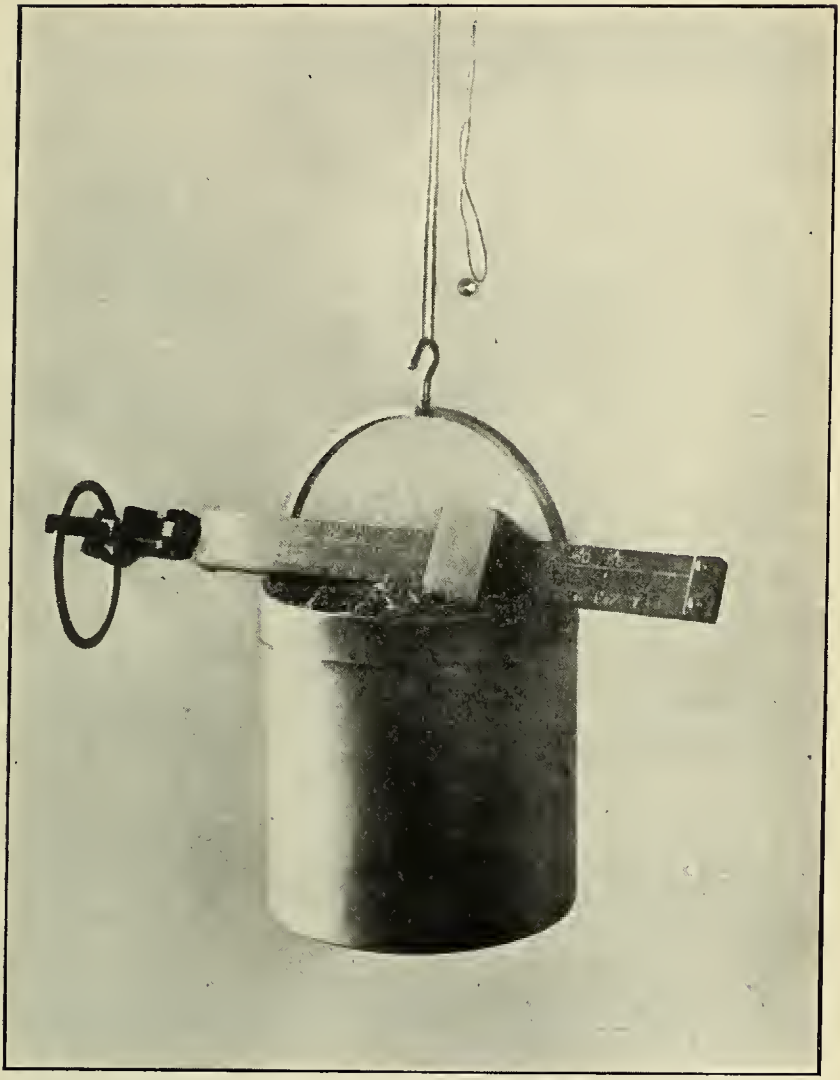

FIG. 43. Standard grain tester. Note the three scales of divisions on the beam.

filling by pouring the grain into the bucket. The probable error of this difference is ±.0529, which clearly signifies that the increase is due to the method of filling and not to chance. The standard deviation of Method II is higher than of Method I. The difference .0503 is slightly less than twice the probable error ±.0264 showing that the two methods are about equal in variability. Further evidence of this is shown in the coefficients of variability which differ by .0369±.1044 the difference being less than its probable error.

TABLE 2.

Variation Constants in Weight per Bushel of Lincoln Oats.

METHOD.	MEAN. Per cent.	MEAN. Weight per bushel —lbs.	Standard deviation —lbs.	Coefficient of variation.
I	54.090	34.6176±.0357	.5291±.0178	1.5284±.0729
II	57.835	37.0144±.0391	.5794±.0195	1.5653±.0747
III	58.585	37.4944±.0320	.4744±.0160	1.2653±.0604
IV.	60.385	38.6464±.0219	.3254±.0110	0.8420±.0402

When the grain is settled by shaking, the mean weight per bushel is greatly increased. This is seen by comparing Method IV with Method I. The mean weight per bushel according to Method IV is 4.0288±.0419 lbs. higher than that of Method I. Such a difference, 100 times its probable error, clearly signifies that the higher mean is due to the method of handling the grain. In addition to raising the mean, Method IV also lowers the standard deviation by the amount of .2037±.0209 lbs. This difference is significant in that it is about 10 times its probable error. Hence it is clear that settling the grain lessens the variability of the determinations. This is further substantiated in the coefficients of variation. Here the difference is 0.6864, which is about 8 times its probable error ±.0833. Similarly the effect of shaking is shown in Method III as compared with Method II. One shaking raises the mean 0.4800±.0505 lbs. and lowers the standard deviation .1050±.0232 lbs. The relative variability also decreases, as is seen in the coefficients of variation, giving a difference of 0.3000±.0061. In each of these the magnitude of the difference in relation to its probable

error is sufficient to lead one to conclude that even one shaking in settling the grain manifests itself in a higher mean and a smaller variability.

In all of these methods it is evident that the standard deviation and the coefficient of variation are absolutely small. While shaking five times lowers the variability of the mean weight determinations as is shown in a reduction of 38.5 percent in the standard deviation and 44.9 percent in the coefficient of variation, the mean weight per bushel increases 11.6 percent. On account of its very low standard deviation and coefficient of variation Method IV has been adopted by this Station as the one giving the greatest accuracy in determinations of the bushel weight of oats. In our tests of varieties of oats the practice is to take for each variety the mean of three weighings as the weight per measured bushel. This gives us according to the results derived from data presented in this paper a measurement possessing a very high degree of accuracy. Method I we understand is the one ordinarily practised by grain dealers, and the data shown herein warrant the conclusion that determinations derived thereby also possess a high degree of accuracy. However, as already shown, this degree of accuracy is very much less than that attainable in Method IV.

The use of the standard bushel measure in getting the weight of seeds heavier than oats would undoubtedly show less variation in the determinations.

SUMMARY.

Data presented in this paper indicate the necessity of following a particular scheme of handling the standard grain tester in determining the weight per bushel of grain.

Of the four methods tried the one wherein the grain is poured into the bucket and settled by shaking five times gives the most accurate results. This method in comparison with that involving no settling of the grain lowers the standard deviation 38.5 percent and the coefficient of variation 44.9 percent.

Settling the grain not only decreases the range of variability, thus giving more accurate results, but also increases the mean weight per bushel.

In conclusion it can be said that the standard grain tester as a means of determining the weight per measured bushel of grain gives results possessing a high degree of accuracy.

NOTE ON THE INFLUENCE OF SHAPE AND SIZE OF PLOTS IN TESTS OF VARIETIES OF GRAIN.*

By Clarence W. Barber.

Experience in testing varieties of oats in rows under cultivation, in small and large plots, and under field conditions, impresses one with the widely variable results obtained in the propagation of oats in different allowances of space for development. In variety tests it is customary to surround each plot with a pathway which is generally kept clear of weeds and other plants by cultivation. This passageway not only permits close observation of the plants within the plot but also prevents the mixture of varieties at the time of planting and at harvest. Observation of oats grown in plots thus separated often presents a marked contrast in respect to the productivity of plants situated along the borders of the plots as compared with plants growing within the plot. This thriftiness of marginal plants is exemplified in a greater number of culms per plant, a higher yield of grain, and a longer period of growth. Generally the marginal plants thrive in a green condition several days after the plants in the center of the plot have begun to ripen. As an illustration of the cropping ability of a strain of oats under different conditions may be cited the performance of a Line No. 286 of oats originated by the Maine Agricultural Experiment Station. In a plant breeding garden where one seed was dropped at each three inch interval in drills one foot apart, this line of oats yielded at the rate of 11.3 grams of grain per plant. In two two-thousandth acre plots for this same line the average production of grain per plant amounted to 2.94 grams. In the latter case seed was planted at intervals of one and one-half inches in drills four inches apart. In the first instance each plant was allotted thirty-six square inches; in the second instance six square inches. The yield per plant in the larger space was nearly four times that of plants grown in the smaller space.

* Papers from the Biological Laboratory of the Maine Agricultural Experiment Station No. 62.

Further evidence of the increased yield attending the growth of plants in an allotment of considerable space is presented in the work of Wacker.* From data given by this author Table I has been formed. In this is shown the yield of grain produced by plants developing under conditions of heavy seeding and light seeding.

TABLE I.

Yield of Grain Plants in Conditions of Heavy and Light Seeding.

	Average number of plants harvested per square meter.	Yield of Grain.	
		Per plant —gms.	Per culm. —gms.
Winter Barley:			
Heavy Seeding	240.9	2.34	0.65
Light Seeding	21.8	29.88	1.64
Winter Rye:			
Heavy Seeding	156.6	4.20	1.35
Light Seeding	16.7	24.26	2.07
Square Head Winter Wheat:			
Heavy Seeding	221.1	2.43	0.86
Light Seeding	20.7	21.90	1.58
Spring Barley:			
Heavy Seeding	141.7	1.56	0.65
Light Seeding	27.4	9.58	1.20

Unfortunately the plots of oats in these tests, so it is stated, were damaged to such an extent as to be of no value. From the figures quoted here one is convinced of the great increase in the yield when grain plants develop in considerable space as compared with plants growing under field conditions. It should be noted that plants grown in the larger space as compared with those grown in the smaller space yield six to thirteen times as much grain per plant or one and a half to two and a half times as much per culm.

In making calculations of the relation between the marginal area and the total area of a plot it was considered a conservative estimate that all plants growing in an area six inches wide within the border of the plot receive benefit from the clean cultivation of the pathways. The basis of this assumption lies

* Wacker: Versuche mit den neuen Getreidekulturverfahren nach Demtschinsky und Zehetmayer. Landw. Jahr. Bd. XLI, 1911.

in the work of Ten Eyck ** and that of Rotmistrov.† The former states that the roots of oat plants growing in drills eight inches apart interlace within two inches of the surface. Rotmistrov found the roots of oat plants of one variety extending laterally 94 cm. or 3.08 ft., of another variety 54 cms. or 1.8 ft. Assuming all the plants in this marginal area to be better developed because of the greater space allotted each plant it may be of interest to plant breeders to point out the relation of this marginal area to the total area of plots of different rectangular shapes and sizes.

The periphery of a unit area in the shape of a square and in rectangular plots having the length 2, 4, 8 or 16 times the width, is considered in Table 2.

TABLE 2.

The Periphery of a Unit Area in Terms of x, x being the Side of a Square of Unit Area

	Square.	Rectangle with length twice width.	Rectangle with length 4 times width.	Rectangle with length 8 times width.	Rectangle with length 16 times width.
Area	x^2	x^2	x^2	x^2	x^2
Width (in feet).	x	$.7071x$ *	$.5000x$	$.3536x$*	$.2500x$
Length (in feet).	x	$2(.7071x)$	$4(.5000x)$	$8(.3536x)$	$16(.2500x)$
Periphery (in feet).	$4x$	$4.2426x$	$5.0000x$	$6.3640x$	$8.5000x$
Per cent. increase in length of periphery on basis of periphery of the same unit area in the form of a square.	–	6.0650%	25.0000%	59.1200%	112.5000%
An area 6 inches wide within the borders in terms of x will be (in sq. ft.).	$2x-1$	$2.1213x-1$	$2.5000x-1$	$3.1824x-1$	$4.2500x-1$

Note: It should be borne in mind that x always refers to the side of a square. Hence, in the use of x the periphery of any oblong plot may be compared directly with that of a square of equal area.

* These factors to six places of decimals are .707107 and .353553. They are derived algebraically as follows:

In a plot with a length two times its width let x represent the width and 1 the area.

$$\text{Then } 2x^2 = 1$$
$$x^2 = .5$$
$$x = .707107$$

In a plot with a length eight times its width, let x represent the width and 1 the area.

$$8x^2 = 1$$
$$x^2 = .125$$
$$x = .353553$$

** Ten Eyck, A. M. The Roots of Plants. Bulletin 127, June 1904. Kansas Expt. Sta.

† Rotmistrov, V. [Distribution of the Roots of Some Annual Cultivated Plants.] Zhur. Opuitn (Russ. Jour. Expt. Landw) 8 (1907), No. 6, pp. 667-705; 9 (1908), No. 1, pp. 1-24.

From Table 2 it is evident that a rectangular unit area in the form of a square possesses the shortest periphery and therefore presents the smallest number of plants along its borders. As shown in this table, a change in the shape of a unit area, for example, in the case of its elongation to a length sixteen times its width may subject as many as 112.5 per cent more plants, as compared with those of the same unit area in the form of a square, to the influences arising from marginal conditions. An increase in the length of a plot increases the number of plants along the margin.

What has been said here holds true for plots sown broadcast, as well as for those seeded in drills. Each unit within the margins of a broadcasted plot supports, according to the laws of chance, a number of plants numerically equal to those of every other unit of the plot. The same is true in drilled plots. A plot in which seed is sown in drills six inches apart is divided into equal areas six inches wide. Each of these receives on the average the same number of seeds and supports equal numbers of plants according to the laws of chance. Hence an area six inches wide within the margins of a plot contains the same number of plants as an equal area within the plot. It should be pointed out here that a circular plot of a unit area has the shortest periphery and therefore presents the smallest number of plants along the border. However, the impracticability of seeding and handling plots of this shape is obvious.

TABLE 3.

The Relation of an Area Six Inches Wide Within the Border of a Plot to the Total Area of the Plot.

SIZE OF PLOT.	Shape of plot.	Dimensions of plot.	Length of periphery.	Area of strip six inches wide within border in sq. ft.	Per cent. of total area lying in a strip six inches wide within the border.	Per cent. increase in area of six-inch strip on basis of area in square.
2000th acre	Square	4.67x4.67	18.67	8.33	38.26	–
" "	Length 2 times width	3.30x6.60	19.80	8.90	40.86	6.79
" "	Length 4 times width	2.33x9.33	23.33	10.67	48.98	28.00
1000th acre	Square	6.60x6.60	26.40	12.20	28.01	–
" "	Length 2 times width	4.67x9.33	28.00	13.00	29.85	6.56

TABLE 3—Concluded.

SIZE OF PLOT.	Shape of plot.	Dimensions of plot.	Length of periphery.	Area of strip six inches wide within border in sq. ft.	Per cent. of total area lying in a strip six inches wide within the border.	Per cent. increase in area of six-inch strip on basis of area in square.
1000th acre	Length 4 times width	3.30x13.20	33.00	15.50	35.58	27.05
500th acre	Square	9.33x9.33	37.34	17.67	20.28	–
" "	Length 2 times width	6.60x13.20	39.60	18.80	21.58	6.41
" "	Length 4 times width	4.67x18.67	46.67	22.33	25.64	26.41
250th acre	Square	13.20x13.20	52.80	25.40	14.58	–
" "	Length 2 times width	9.33x18.67	56.00	27.00	15.50	6.35
" "	Length 4 times width	6.60x26.40	66.00	32.00	18.37	25.98
100th acre	Square	20.87x20.87	83.48	40.74	9.35	–
" "	Length 2 times width	14.76x29.52	88.55	43.27	9.93	6.22
" "	Length 4 times width	10.44x41.74	104.36	51.18	11.75	25.61
" "	Length 8 times width	7.38x59.03	132.82	65.41	15.02	60.55
" "	Length 16 times width	5.22x83.48	177.40	87.70	20.13	115.26
50th acre	Square	29.52x29.52	118.06	58.03	6.66	–
" "	Length 2 times width	20.87x41.74	125.23	61.61	7.07	6.17
" "	Length 4 times width	14.76x59.03	147.58	72.79	8.36	25.43
" "	Length 8 times width	10.44x83.48	187.84	92.92	10.67	60.12
" "	Length 16 times width	7.38x118.06	250.89	124.44	14.28	114.44
40th acre	Square	33.00x33.00	132.00	65.00	5.97	–
" "	Length 2 times width	23.33x46.67	140.01	69.00	6.34	6.16
" "	Length 4 times width	16.50x66.00	165.00	81.50	7.48	25.38
" "	Length 8 times width	11.67x93.34	210.01	104.01	9.55	60.01
" "	Length 16 times width	8.25x132.00	280.50	139.25	12.79	114.23
20th acre	Square	46.67x46.67	186.68	92.34	4.24	–
" "	Length 2 times width	33.00x66.00	198.00	98.00	4.50	6.13
" "	Length 4 times width	23.33x93.34	233.35	115.67	5.31	25.27
" "	Length 8 times width	16.50x132.00	297.00	147.50	6.77	59.74
" "	Length 16 times width	11.67x186.68	396.69	197.34	9.06	113.72
10th acre	Square	66.00x66.00	264.00	131.00	3.01	–
" "	Length 2 times width	46.67x93.34	280.01	139.01	3.19	6.11
" "	Length 4 times width	33.00x132.00	330.00	164.00	3.76	25.19
" "	Length 8 times width	23.33x186.68	420.02	209.01	4.80	59.55
" "	Length 16 times width	16.50x264.00	561.00	279.50	6.42	113.36
1 acre	Square	208.71x208.71	834.84	416.42	0.96	–
1 "	Length 2 times width	147.58x295.16	885.48	441.74	1.01	6.08
1 "	Length 4 times width	104.36x417.42	1043.55	520.78	1.20	25.06
1 "	Length 8 times width	73.79x590.32	1328.22	663.11	1.52	59.24
1 "	Length 16 times width	58.18x834.84	1774.04	886.02	2.03	112.77

Table 3 shows the percentage of the total area contained in a strip six inches wide within the border of plot units commonly used in plant breeding tests. It will be noted that the part of a square plot lying in this marginal strip ranges from 0.96 percent in an acre area to 38.26 per cent in a 2000th acre area. In a plot with a length two times its width this marginal area amounts to 1.01 per cent in an acre and 40.86 per cent in a 2000th acre area. The percent of the total area lying in the strip six inches wide within the border of a long narrow plot is much greater than that of a square plot of the same area. In the cases considered the marginal area may be 6 percent to 115 percent greater in long plots than in square plots of equal size. The magnitude of this percentage depends on the relation of the length to the breadth of the plot.

Mercer and Hall * maintain that there is practically no difference in the accuracy of square plots and long narrow plots. However, it should be borne in mind that the basis of the conclusions of these authors was the yield of an acre plot selected out of a large field. This acre was divided into small units each of which was harvested separately. There were no pathways around the acre plot and likewise, and of much greater importance, none around the small units of the acre. Hence their conclusions are based on conditions where the competition among plants is that ordinarily found in any field. These authors *do not consider* the possible effect of pathways around plots. Nevertheless the marginal plants play an important part in making up the total yield of plots.

To overcome the influence of pathways it has often been suggested as advisable to discard the outside rows of a plot in order to attain a fairer test of the cropping ability of a variety of grain under so-called normal conditions. However, to throw away the outside rows of each plot is exceedingly bad practise in plant breeding work because of the possibility of such odds and ends becoming mixed up with other varieties. Further the discarding of outside rows requires a greater labor expense and also greater land area in attaining results on unit plots. Trimming plots to overcome certain effects of environment is ex-

*Mercer, S. W. and Hall, A. D. The Experimental Error of Field Trials. The Journal of Agricultural Science, Oct. 1911.

ceedingly unsatisfactory. The best practice in plant breeding work is to plant in a plot only what one wants to harvest therefrom. All in all, as long as conditions are similar for all varieties of grain in trial in a field of fairly uniform soil, the results of plot tests will show the relative yields of the varieties.

The use of small unit areas in plant breeding work is necessary in the propagation of selected plants, especially because of the great number of such selections one must try out in the search for superior individuals. It is often impossible during the first season following propagation in head rows to carry out tests on units larger than a thousandth or a five hundredth of an acre. The calculated yields per acre obtained on such small areas are generally a great deal higher than those gotten by growing the same variety in large plots. Mercer and Hall have pointed out that a large error due to soil variation and other factors is involved in tests on such small areas. These authors show that in plots smaller than a fortieth or fiftieth acre the error of the yields rises rapidly as the area of the plot diminishes. However an increase in the size of a plot above a fortieth or fiftieth acre does not give results of sufficiently greater accuracy to warrant the greater expense involved in the use of larger units. By testing varieties in four or five units of 40th or 50th acre size they show the error of the results to be much smaller. In addition to the error worked out by these authors there must be in plots surrounded by paths another factor which augments the productivity of the marginal plants. As already pointed out this factor brings the shape as well as the size of plot into consideration.

From the foregoing discussion it is evident that a means of gauging approximately the cropping ability of a variety of grain in a field on the basis of what it does in small areas would be of some service. Undoubtedly an absolutely accurate measure can not be determined for forecasting on the basis of performance in small areas the probable productivity of an oat under field conditions. However, it may be possible to arrive at a fair estimate. To be able to do this would prove of great assistance in judging the possible worth of pure lines which have been propagated to the point of enabling tests in 500th acre plots. Then, at the beginning of the search for superior strains it is desirable to approximately estimate their worth as

compared with the varieties already established. Of course a check on the productivity of new varieties may be had by planting several plots to one commercial variety regularly distributed throughout the field. Even with this, an additional means of gauging the value of a new strain would be advantageous. The importance of the size and shape of a plot impresses one forcibly when it is considered that marginal plants may yield twice as much as plants within the plot. In this event any yield of a variety grown on 50th acre units would have to be considered as 106.7 percent, on a 100th acre 109 percent, on a 1000th acre 128 percent according to figures given in Table 2.

In oblong plots of these unit areas the percent would be much higher.

This problem of the influence of size and shape of plots on the results of variety tests of grain may be viewed from the standpoint of marginal drill length in comparison with the total drill length in a plot. In this the plants within six inches of the border at each end of a drill are considered subject to the conditions outside the margin and, hence, make up a row across each end of the plot.

In terms of x, x representing the side of a square, a unit area x^2 in different rectangular shapes will have the dimensions given in Table 4 Also one will note in this table the length of the marginal drills and the total drill length together with the relation between marginal drill length and total drill length.

TABLE 4.

Relation of Marginal Drill Length to Total Drill Length.

SHAPE OF PLOT.	Square.	Length 2 times width.	Length 4 times width.	Length 8 times width.	Length 16 times width.
Area	x^2	x^2	x^2	x^2	x^2
Width in feet	x	$0.7071x$	$\frac{x}{2}$	$.3536x$	$\frac{x}{4}$
Length (of rows) in feet	x	$1.4142x$	$4\frac{x}{2}$	$2.8284x$	$16\frac{x}{4}$
Total number of drills of x length in feet ½ ft. apart	$2x$	$1.4142x$	x	$.7071x$	$\frac{x}{2}$
Total length in feet of all drills	$2x^2$	$2x^2$	$2x^2$	$2x^2$	$2x^2$
Length in feet of marginal drills	$4x-2$*	$4.2426x-2$	$5x-2$	$6.364x-2$	$8.5x-2$
Ratio of marginal drill length to total drill length	$\frac{2x-1}{x^2}$	$\frac{2.1213x-1}{x^2}$	$\frac{2.5x-1}{x^2}$	$\frac{3.182x-1}{x^2}$	$\frac{4.25x-1}{x^2}$

* In a plot in which the drills are spaced six inches apart two feet must be subtracted from the periphery to avoid duplication of drills in the corners.

It is obvious that in oblong plots having fewer and longer drills than a square plot of the same area the ratio of the marginal drill length to the total drill length is greater.

Kiessling * refers to the fact that in small narrow plots the ratio of the plants in border rows to the total plants is greater than in large plots.

SUMMARY.

The purpose of this paper is to show:

1. That since in plots surrounded by cultivated pathways the plants along the margins are more productive than those within the plot, it is evident that shape as well as size of plot must be considered in tests of varieties.

2. Of rectangular plots of a unit area a square has the shortest periphery and accordingly presents the smallest number of plants along the borders. Therefore *a square plot is a more accurate basis for the determination of the value of varieties than any other rectangular shaped plot of equal area.* It is clear that in a long narrow plot more plants will be subjected to the conditions afforded by the pathways than in a square of the same area. Also, in small plots proportionately more plants will stand along the border than in large plots.

3. Mercer and Hall (*loc. cit.*) do not consider the effect of pathways surrounding plots. Hence their conclusion that the shape of plots does not affect the results of tests of varieties is not tenable in the case of plots surrounded by pathways.

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* Kiessling, L. Einiges aus der Praxis des Zuchtgartenbetriebes. Zeit. f. Pflanzenzüchtung, Bd. 1, Heft, 1, December 1912.

A TABLE FOR ESTIMATING THE PROBABLE SIGNIFICANCE OF STATISTICAL CONSTANTS.*

By Raymond Pearl and John Rice Miner.

The use of biometric methods in biology and related applied sciences is becoming all the time more general. The increasing use of this technique is not, however, entirely free from doubtful features. Biometric methods and biometric conclusions *per se* are not infallible. To use them safely and profitably demands a clear understanding of this real meaning, so that a specious air of profundity and infallibility may not be given to results which in reality lack these qualities. The present note is offered as a slight numerical aid to sanity and conservatism in statistical investigations.

One of the most important of the contributions of biometry is its insistence on the "probable error" as a test of the probable validity of conclusions. This is an entirely commendable tendency. But there has grown up a certain conventional way of interpreting probable errors, which is accepted by many workers, not all of whom are beginners, without any critical examination of the real basis of the conventional usage. It has been practically a universal custom amongst biometric workers to say that a difference (or a constant) which is smaller than twice its probable error is probably not significant, whereas a difference (or constant) which is three or more times its probable error is either "certainly" or at least "almost certainly" significant.

Now such statements as these derive whatever meaning they may possibly have from the following simple mathematical considerations. Assuming ** that the errors of random sampling are distributed strictly in accordance with the normal or

* Papers from the Biological Laboratory of the Maine Agricultural Experiment Station, No. 63.

** In the present connection we are in no way concerned with the generality or degree of validity of this assumption. It has been extensively and adequately dealt with by Pearson and his students in many papers. In most cases this assumption is sufficiently accurate for practical purposes.

Gaussian curve it is a simple matter to determine from any table of the probability integral the precise portion of the area of a normal curve lying outside any original abscissal limits, or in other words, the probability of the occurrence of a deviation as great as or greater than the assigned deviation. To say that a deviation as great or greater than three times the probable error is "certainly significant" means, strictly speaking, that the area of the normal curve beyond 3 P. E. on either side of the central ordinate is negligibly small. As a matter of fact this is not true, unless one chooses to regard 4.3 per cent. as a negligible fraction of a quantity. There are certainly many common affairs of life in which it would mean disaster to "neglect" a deviation of four percent of the total quantity involved.

It seems likely that it may be useful to statistical workers to have at hand a small table which will set forth for a series of ratios between a statistical deviation and the "probable error"* of the error distribution, first the probability that a deviation as great as or greater than the given one will occur, and second the odds against the occurrence of such a deviation. Such a table is appended hereto. In calculating it we have used Sheppard's † tables of the probability integral, changing from arguments in terms of standard deviation to arguments in terms of probable error. The probabilities have been expressed on a percentage basis, on the ground that they will probably in this way make a more direct appeal to the average mind, since we are more accustomed to thinking in terms of parts per 100 than per any other number.

A single example will indicate how the table is to be used. Suppose one has determined the mean of each of two com-

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* As many statistical writers have pointed out, the convention of using the "probable error" rather than the standard deviation of a distribution as a measure of its "scatter" is unfortunate. Yule (Introduction to the Theory of Statistics) has made recently a strong plea for the use of the "standard error." It however seems likely that the probable error is too strongly entrenched in the common usage now to be dislodged.

† Biometrika Vol. II, pp. 174-190.

parable series of measurements. These means differ by a certain amount. The difference is found to be, let us say, 3.2 times as large as the probable error of the difference. Is one mean *significantly* larger than the other? Or, put in another way, what is the probability that the difference arose purely as a result of random sampling (as a result solely of chance)? Under the argument 3.2 in the table we find the probability of the occurrence of a deviation as great or greater than this to be 3.09. This means that in every 100 trials a deviation of this size or greater would be expected to occur, as result of chance alone, (the error of random sampling), 3.09 times. Or, from the next column, the odds against the occurrence of a difference as great or greater than this in proportion to its probable error, are 31.36 to 1, if chance alone were operative in the determination of the event. If one wants to call this "certainty" he has a perfect right to do so. The table merely defines quantitatively his particular conception of certainty.

It will be noted that after the ratio, deviation ÷ P. E., passes 3.0 the odds against the deviation increase rapidly, reaching a magnitude at 8.0 which is, practically speaking, beyond any real power of conception. We have started the table at 1.0, because this is the point where the chances are even. A deviation as large as the probable error is as likely to occur as not, and *vice versa*.

TABLE I.

Showing the Probability of Occurrence of Statistical Deviations of Different Magnitudes Relative to the Probable Error.

Deviation / P. E.	Probable occurrence of a deviation as great as or greater than designated one in 100 trials.	Odds against the occurrence of a deviation as great as or greater than the designated one.	Deviation / P. E.	Probable occurrence of a deviation as great or greater than the designated one in 100 trials.	Odds against the occurrence of a deviation as great as or greater than the designated one.
1.0	50.00	1.00 to 1	3.5	1.82	53.95 to 1
1.1	45.81	1.18 to 1	3.6	1.52	64.79 to 1
1.2	41.83	1.39 to 1	3.7	1.26	78.37 to 1
1.3	38.06	1.63 to 1	3.8	1.04	95.15 to 1
1.4	34.50	1.90 to 1	3.9	.853	116.23 to 1
1.5	31.17	2.21 to 1	4.0	.698	142.26 to 1
1.6	28.05	2.57 to 1	4.1	.569	174.75 to 1
1.7	25.15	2.98 to 1	4.2	.461	215.92 to 1
1.8	22.47	3.45 to 1	4.3	.373	267.10 to 1
1.9	20.00	4.00 to 1	4.4	.300	332.33 to 1
2.0	17.73	4.64 to 1	4.5	.240	415.67 to 1
2.1	15.67	5.38 to 1	4.6	.192	519.83 to 1
2.2	13.78	6.26 to 1	4.7	.152	656.89 to 1
2.3	12.08	7.28 to 1	4.8	.121	825.45 to 1
2.4	10.55	8.48 to 1	4.9	.095	1051.63 to 1
2.5	9.18	9.89 to 1	5.0	.074	1350.35 to 1
2.6	7.95	11.58 to 1	6.0	.0052	19,230 to 1
2.7	6.86	13.58 to 1	7.0	.00023	434,782 to 1
2.8	5.90	15.95 to 1	8.0	.000000068	1,470,588,234 to 1
2.9	5.05	18.80 to 1			
3.0	4.30	22.26 to 1			
3.1	3.65	26.40 to 1			
3.2	3.09	31.36 to 1			
3.3	2.60	37.46 to 1			
3.4	2.18	44.87 to 1			